Advances in Continuous Glucose Monitoring Systems: A Systematic Review of Sensor Technologies and Mobile Health Integration

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Several studies have focused on the evolution of Continuous Glucose Monitoring Systems (CGMS), particularly regarding their integration with mobile devices and the application of predictive strategies. Considering the increasing relevance of this technology in the healthcare sector, this systematic literature review aims to explore recent scientific advances, highlighting the main types of sensors, algorithms, and connectivity solutions described in the selected studies. The included articles presented innovative approaches involving microwave and electrochemical sensors, as well as techniques for glycemic trend prediction and mobile communication. The findings indicate significant progress in the development of CGMS, especially in real-time monitoring capabilities and the integration of artificial intelligence models for data analysis. However, challenges remain, such as improving sensor sensitivity and specificity, achieving clinical validation in real-life scenarios, and ensuring interoperability between different platforms and devices. The literature also emphasizes the importance of advancing user-centered design, data privacy, and regulatory compliance to facilitate the adoption of these systems in both clinical and personal health monitoring contexts. It is concluded that expanding the technological maturity and accessibility of CGMS is essential to support personalized diabetes management and to improve the quality of life for patients worldwide.
Keywords: Continuous Glucose Monitoring. Sensor Technologies. Mobile Health Integration. Predictive Algorithms.
Abbreviations: CGMS, Continuous Glucose Monitoring Systems; SLR, Systematic Literature Review.

Continuous Glucose Monitoring Systems (CGMS) represent a significant technological advancement in the management of diabetes mellitus, offering a dynamic and real-time method for tracking fluctuations in blood glucose levels throughout the day and night [1]. Unlike traditional methods such as finger-prick capillary blood glucose testing, which provides only isolated snapshots of glycemic status, CGMS enable the continuous collection of interstitial glucose data, allowing for the identification of patterns, trends, and critical fluctuations that may otherwise go undetected. This continuous feedback facilitates timely clinical decision-making, enhances individualized treatment plans, and plays a crucial role in preventing acute complications such as hypoglycemia and hyperglycemia [2].

As the global prevalence of diabetes continues to rise—fueled by aging populations, urban lifestyles, and dietary changes—there is a growing demand for monitoring strategies that are not only clinically effective but also accessible, user friendly, and economically sustainable, especially in resource-constrained settings [3]. Traditional CGMS technologies, although clinically validated, are often limited by their high cost, limited availability in public health systems, and the need for frequent sensor replacement, which restricts their widespread adoption [4].

In response to these challenges, the development of next-generation CGMS has increasingly focused on creating low-cost, minimally invasive or non-invasive solutions [5] that can be seamlessly integrated with mobile devices such as smartphones and smartwatches. These innovations aim to expand the reach of glucose monitoring technologies beyond hospital settings, enabling remote patient monitoring, real-time alerts, and

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data-driven interventions. The integration with mobile platforms also opens possibilities for incorporating additional functionalities, including cloud-based analytics, artificial intelligence (AI) for glycemic pattern prediction, and improved user engagement through mobile health (mHealth) applications [6].

Although commercial CGMS devices have demonstrated proven effectiveness, their high cost remains a barrier to large-scale adoption, particularly within public healthcare systems [7]. Furthermore, there are still limitations regarding full integration with mobile platforms and a lack of robust clinical validation in real-world settings [8].

The incorporation of mobile devices into the CGMS ecosystem has proven to be a critical factor in improving treatment adherence and user engagement, especially through wearable technologies that promote autonomy and personalized monitoring [9].

The present systematic literature review aims to answer the following research question: What are the advances, challenges, and trends in the development of low-cost Continuous Glucose Monitoring Systems with mobile integration and predictive potential?

The general objective of this study is to identify, analyze, and synthesize emerging technological solutions for sensors applied to CGMS, with an emphasis on low-cost approaches, mobile integration, and predictive strategies. Specifically, the study aims to: (i) characterize the types of sensors used; (ii) describe the transmission technologies and integration platforms involved; (iii) identify the predictive analysis strategies adopted; and (iv) highlight research gaps and future directions.

Materials and Methods

The methodology adopted in this study was based on the model proposed by Kitchenham and Charters [10] in a systematic literature review applied to software engineering. Accordingly, the concept of SLR (Systematic Literature Review) was adapted to the proposed topic. The methodological process involved four main stages: definition of the research question, development of the search strategy, application of eligibility criteria, and data extraction and analysis.

Search Sources and Research Strategies

The bibliographic search covered the following scientific databases: IEEE Xplore, PubMed, Scopus, ScienceDirect, Web of Science, and Google Scholar — the latter used as a complementary source to expand coverage and identify academic works not indexed in traditional databases.

The search strategy was structured around five main thematic axes: (i) continuous glucose monitoring; (ii) sensors and biosensors; (iii) low-cost technologies; (iv) integration with mobile devices and digital health; and (v) predictive approaches to glycemic events. To this end, descriptors were used, combined with Boolean operators. The main search terms included: "continuous glucose monitoring", "low cost", "affordable", "biosensor", "sensor technology", "mobile health", "Bluetooth", "smartphone", "data analytics", "prediction", and "hypoglycemia".

Search terms were adapted according to the structure and features of each database. Initially, only a temporal filter (2015 to 2025) was applied to ensure the relevance and timeliness of the studies. The types of documents considered included scientific articles, theses, dissertations, reviews, and book chapters.

Inclusion and Exclusion Criteria

In addition to the temporal delimitation, this review considered studies published in Portuguese, English, or Spanish that investigated technologies applied to continuous glucose monitoring. Eligible studies addressed the development of economically viable sensor devices, connectivity with mobile technologies and digital health solutions, the use of analytical models for predicting glycemic events, as well as technical advancements and clinical outcomes related to the implementation of such systems.

Studies with overlapping content, conference abstracts without full-text articles, duplicated records across different databases, and research focused exclusively on theoretical discussions related to diabetes pathophysiology, metabolic processes, or clinical perspectives unlinked to the development, evaluation, or application of technological solutions were excluded.

Data Extraction

After conducting the searches in the selected databases, the results were imported into Zotero, a reference management software that also offers functionalities for organizing and screening studies in systematic reviews. Through Zotero, it was possible to identify and remove duplicate records, assign tags based on predefined inclusion and exclusion criteria, and perform title and abstract screening, ensuring greater transparency, consistency, and traceability in the selection process.

The studies considered potentially eligible were then assessed in full text to verify their alignment with the objectives of this review. Bibliographic data and relevant study information were extracted and organized within Zotero. In parallel, the extracted variables were systematized in structured Microsoft Excel spreadsheets, using standardized fields such as authorship, year of publication, type of sensor, predictive approach, transmission technology, integration with mobile platforms, estimated cost, reported impacts, and key methodological notes.

In addition to these objective elements, representative textual excerpts were also extracted from the full texts, specifically related to the following categories: main findings, reported limitations, and identified gaps and recommendations. This qualitative layer of analysis guided the interpretative selection of content directly from the articles, contributing to a deeper understanding of the evidence and informing the discussion of the review's findings. The triangulation between technical variables and textual excerpts enabled the identification of recurring patterns, contradictions, emerging technological trends, and methodological gaps, thereby enhancing the analytical depth and explanatory power of the review.

Results and Discussion

The Table 1 shows the search results, a total of 464 references were initially retrieved from the selected databases. The study selection process was conducted sequentially through progressive filtering steps.

Table 1. Search results in scientific databases.

Scientific Databases	Number of Items
Google Scholar	20
IEEE Xplore	88
CAPES	30
PUBMed	130
Scopus	114
Web of Science	18
ScienceDirect	64

In the first stage, 97 potential duplicates were identified. After evaluating titles and DOIs—considering that some studies appeared in more than two databases—51 records were excluded. This step resulted in 413 unique references.

Next, keyword filtering was applied to exclude studies involving animal models, using terms such as *in vitro*, rat, rats, animal, and animals. This step excluded 26 studies, reducing the dataset to 387 references.

In the following step, additional terms such as insulin and sensitivity were used to exclude studies focused on insulin-related mechanisms. A total of 33 records were removed, resulting in 354 references.

Subsequently, a temporal filter was applied, excluding studies published before 2015, in accordance with the eligibility criteria. This step removed 94 studies, leaving 260.

Finally, a thematic scope analysis was performed to exclude studies with a purely clinical, metabolic, or pathophysiological focus unrelated to technological applications in glucose monitoring. This step led to the exclusion of 183 studies, with 77 references selected for full-text reading and in-depth analysis and 10 were selected for reading. The Figure 1 summarizes this flow.

The data extraction phase included ten selected studies that proposed sensor technologies. The devices analyzed exhibit diversity in technological principles, transmission mechanisms, analytical strategies, and modes of integration with mobile platforms.

Sensor types vary across microwave-based systems (including antennas and dual-band structures), optical biosensors (featuring technologies such as nanopillar SPR), and electrochemical sensors (including three-electrode amperometric systems and flexible sensors). Near-infrared spectroscopy (NIR)-based solutions were also identified.

Regarding data transmission, most studies employed wireless technologies such as Bluetooth, Bluetooth Low Energy, NFC, microwave networks, integrated circuits with microcontrollers, and ISM-band radar modules. These transmission systems are generally designed to communicate with mobile applications or wearable devices.

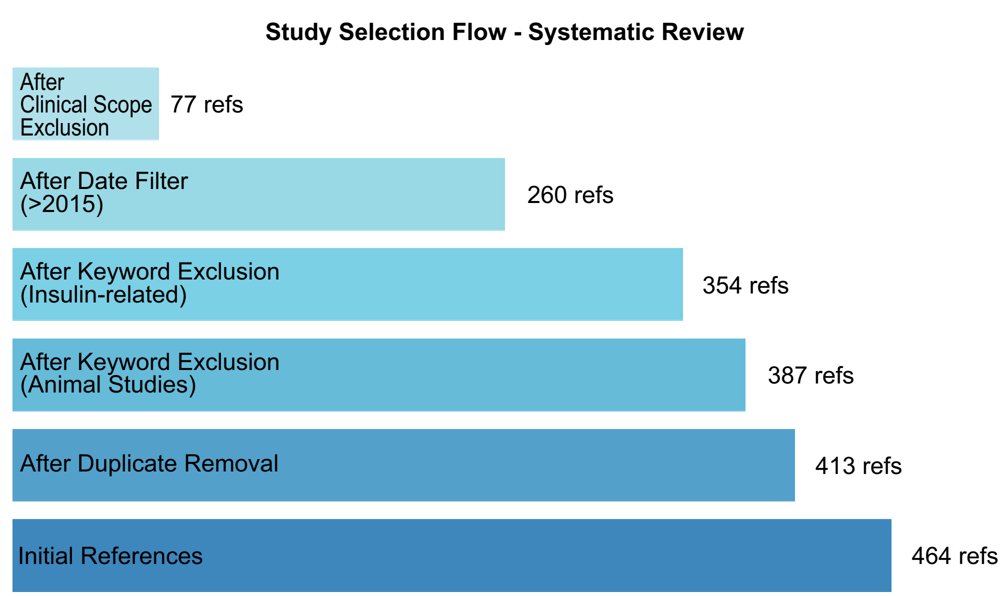
In terms of analytical approaches, the predictive strategies reported include regression algorithms, real-time signal detection with defined detection limits, signal correlation for calibration, and Sparameter analysis—some of which are associated with machine learning techniques.

Integration with mobile platforms is mentioned in nearly all studies, either through smartphone applications, wearable system connectivity, or references to interoperability with electronic health records. Only a few articles do not explicitly detail this aspect, although they imply it as part of the proposed architecture.

When reported, cost estimates reflect a focus on affordability, with explicit mention of low-cost prototypes or economical design strategies. However, in many cases, cost data are not precisely quantified.

The studies included in this systematic review reflect a growing effort in the literature to develop non-invasive and affordable technologies for CGMS. Despite the diversity of sensors and

Figure 1. Study selection flow – Systematic Review.



technical approaches, there is a common trend toward portability and integration with mobile devices, which supports their use in both clinical and home-based settings.

Connectivity with digital platforms—such as mobile applications and wearable systems—is a recurring feature, with potential to enhance remote monitoring and promote greater autonomy in diabetes management. Additionally, analytical strategies like statistical regression and machine learning algorithms are being incorporated into systems for glycemic event prediction, although often applied in simulated conditions.

From a methodological standpoint, important limitations were observed, including the lack of robust clinical validation, small sample sizes, and a lack of standardization in data presentation. Technical terms such as "low cost" or "high accuracy" are frequently used without reference to clear metrics, which hinders comparisons between studies and the generalization of results.

Conclusion

This systematic review highlighted significant advancements in the field of CGMS, with particular emphasis on innovations in alternative sensor technologies, increased integration with mobile platforms, and the adoption of predictive strategies based on computational intelligence. The analysis of ten studies — five of which were examined in depth — revealed a promising technological landscape, albeit marked by ongoing challenges related to methodological standardization, clinical validation, and large-scale feasibility.

The main contribution of this review lies in identifying the convergence of low cost, connectivity, and analytical capabilities as key pillars for the development of more accessible and effective diabetes management solutions. Despite notable progress, critical gaps remain, particularly regarding practical validation, user experience, and integration with public healthcare systems.

Future research should prioritize empirical assessments of CGMS devices, focusing on usability, scalability, and social impact. Additionally, the use of more rigorous and reproducible data extraction protocols — such as the one employed in this review — is essential to strengthen the evidence base and improve comparability across studies.

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